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EFFECT OF SIDE SLOPES OF TRAPEZOIDAL CHANNEL ON MAXIMUM SCOUR DEPTH DOWNSTREAM OF TRANSITION

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ABSTRACT

When a hydraulic structure is constructed in a non-rectangular section of an open channel, a transition length is a must. The structure is normally erected in a rectangular contracted section to minimize the costs. Downstream (DS) from the transition, the original section started gradually and sometimes abruptly. In this paper, an experimental investigation is conducted to explore the effect of symmetric side slopes of trapezoidal channel section started abruptly downstream the transition length. Different side slopes of the channel section are tested in the range from 0:1 to 0.35:1. The optimal value of the side slope that minimize the local scour in the trapezoidal channel DS the transition is concluded. The experiments are conducted in a laboratory flume of 0.3 m wide, 0.45 m high and 12.5 m long. In the transition length upstream the trapezoidal channel, an angled-guide wall of thin thickness, particular orientation and fixed location is used to reduce the scour process. The flow and scour patterns are analyzed. Empirical equations in terms of the Froude number and the side slopes of the channel section are developed with an acceptable error range.

KEYWORDS:

Hydraulics, local scour, transition, hydraulic structures, fluid dynamics.

INTRODUCTION

The scouring process DS of vertical gates is an important research topic of value in engineering practice. There are many formulae developed over the years to predict the maximum scour depth at downstream of hydraulic structure, see e.g. Yildiz and Uzucek [4] and Mason and Arumugam [16].

Excessive local scour can progressively undermine the foundation of the structure. Because complete protection against scour is too expensive, generally, the maximum scour depth and the maximum length to the maximum scour related to some datum have to be predicted in order to take the necessary precautions to minimize the risk of failure.

Most main and branch canals of the Egyptian irrigation network have trapezoidal cross-section. In the last few decades, the parameters of local scour DS of the regulators have been investigated DS of heading-up structures in rectangular cross-section laboratory flume. Effects of several parameters on scour hole main parameters were investigated including: arrangement of stilling basins [7], grain size of bed materials [6], riprap used for protection [10], erodible sand basin [12], submerged horizontal jet [8] and the effect of time variation [18].

On the other hand, many of researchers investigated different protection methods against scour DS of non-prismatic stilling basins such as: effect of baffle sills over rigid and erodible beds was investigated [3], impact of takeoff angle of bucket type energy dissipater on the scour hole [14],effect of floor reversed jets [13]. Optimal configuration of the central baffled-sill [17] and the end-sill effect [15]. Other investigations of related interest were mentioned in [1].

In addition, a few studies investigated the effect of gate operation on flow and scour parameters such as: design of the sudden expansion and radial stilling basins DS of multi-vent regulators [11], end-sill effect on the free hydraulic jump parameters DS of multi-vent regulators [9], operation effect of two vertical gates on the scour parameters [2] and the effect of different operating systems of multi-vent regulators on scour parameters [5]. To the best of the author information, the survey of the literature indicated that no studies are available on the effect of the side slopes of trapezoidal open channel DS the transition length of the hydraulic structure. For this reason, this study comes on the line to fill the gap and to be a starter on the road.

DEPENDENCE OF SCOUR PARAMETERS

The local scour DS of single-vent regulators through a trapezoidal channel is very complicated phenomenon. The dimensional analysis was employed to drive an expression relating the different variables affecting the phenomena. The general relationship may be written as, see Fig. (1):

$$f\left(b, S, t, b_o, V_1, y_1, y_2, \rho, \nu, g, D_{50}, \rho_s, d_s, L_s\right) = 0 \qquad (1)$$

in which: b is the clear stilling basin width, S is side slope of the channel cross section, b_o is length of opening in the guide wall, V_1 is mean velocity at the initial depth, y_1 is initial depth of hydraulic jump, y_2 is sequent depth of hydraulic jump, ρ is water density, ν is kinematics' viscosity, d_s is maximum scour depth and L_s is maximum protection length. Keeping in mind that t and bo are kept constant, the following functions expressing the scour phenomenon parameters can be presented as follows:

$$ds/y1,\ Ls/y1 = f(f1,\ S) \qquad (2)$$

in which: d_s/y_1 is the relative scour depth and L_s/y_1 is the relative bed length required to be protected against scouring, i.e., relative protection length.

EXPERIMENTAL WORK

The experimental work was carried out in the Hydraulics Laboratory of the Faculty of Engineering, Zagazig University. The experiments were carried out in a re-circulating laboratory flume 30cm wide, 45cm deep with a working section of 12.5m. The discharge was measured using a pre-calibrated orifice-meter installed on a feeding pipeline. The model was made from prespex of thickness 10. The length of the approaching channel was 50 cm. A control sluice gate is made from the same prespex and is used to control the upstream depth and the gate opening. The gate is installed 5 cm upstream the stilling basin. The length of the apron of the rectangular stilling basin is 100 cm. The model DS of gate consisted of single vent 13cm wide, 35.5cm deep and 23cm length. The guide walls width is 8cm. About 2.5 m DS of the apron is covered by sediment consisting of 10 cm sand layer of medium diameter, $D_{50} = 0.885$ mm, see Fig. (1). The tailgate at the end of the flume is used to control the tail water depth. During the course of the experiments, the tailgate is controlled such that the tailwater depth was about 5 cm

Range of discharges and gate openings were used such that the Froude number at the initial water depth of the free hydraulic jump ranged from 1.50 to about 8.83. A total of about 30 runs were performed. The time of each run was chosen to be 45 min based on previous studies, [1]. A typical run consisting of:

- Leveling the movable soil in the test section,
- Adjusting the level of tail gate, using calibration data, to give tail water depth coincides with the desired discharge and gate opening,
- When the water surface US the gate reaches the recalibrated height, the gate is lifted to allow the flow through the required gate opening,
- After the stability conditions are attained, the following measurements are taken: the US water depth, the initial water depth y_1, the sequent water depth y_2 and the tail water depth y_t .
- The water surface profile is recorded starting from the stage US of gates until the steady uniform stage using point gauge and measuring carriage,
- After the required time (45 min.), the flume pump is stopped noting that test time begins with gate lifting,
- The experiment is left until the sand bed is completely dry,
- The sand bed levels are recorded using point gauge and measuring carriage every 5 cm in lateral direction and 10 cm in longitudinal direction till the end of the scour effects to have a complete mesh, and
- At maximum scour hole zone, the bed levels are recorded every 1 cm in both of lateral and longitudinal directions.

The effect of the side slopes of trapezoidal channel on the scour parameters has been examined for six values of s ranging from $s = 0{:}1$ to 0.35:1.

ANALYSIS AND DISCUSSION

The relationships between F_1 and both of ds/y_1 and Ls/y_1 have been presented, for different side slope S, see Fig. (2). It can be noticed that both of ds/y_1 and Ls/y_1 increase as F_1 increases, see Fig. (2a and 2b). Generally, it can be said that, the cross section of side slope $S = 0.29$ reduced the relative scour parameters to minimum limit.

The relationships between cross section of side slope S, and both of ds/y_1 and Ls/y_1 have been presented for different F_1, see Fig. (3). It is clear that, the case of cross section of side slope $S = 0.29$ gives the minimum relative scour parameters for different F_1. It can be reported that for $S \leq 0.29$, the maximum relative scour parameters decrease as S increases for different F_1. In contrast, the maximum relative scour parameters increase as S increases for $S \geq 0.29$, see Fig. (3a and 3b).

Three typical flow and scour patterns at existence of guide walls for different cross section of side slopes and the same F_1 (i.e. F_1=3.13) and were presented as shown in Figs. (4a-c). In fact, there is a great interaction between the cross section side slope and the guide wall itself. *In case of cross section of side slope S less than the optimum value (i.e S* = 0.0), the cross section area of the movable bed became very small and hence the actual flow velocity over the movable bed is clearly magnified. Consequently, the scour process are magnifying, see Fig. (4a). *In case of cross section of side slope S more than the* *optimum one (i.e S* = 0.35), the gross cross section area of the movable bed becomes greater than the previous case, however the net one is still small. Actually, there is an weak zone formed just DS of the sudden expansion. It extends to big distance. As a result, the actual flow velocity over the movable bed is still large. Consequently, the scour process is still critical, see Fig. (4c). *In case of cross section of optimum side slope S (i.e S* = 0.29), the interaction between the guide walls and cross section slope controlled the weak zone formed just DS of the sudden expansion, see Fig. (4b). Actually, the net cross section area of the movable bed becomes greater than the previous case. It leads to reduce the actual flow velocity over the movable bed is. Consequently, the scour process is clearly minified, see Fig. (4b).

ESTIMATION OF MAIN SCOUR PARAMETERS

Using all the experimental data of the relative scour depth and the relative protection length, a prediction models were developed and verified using the multiple linear regression analysis, as follows:

$$d_s / y_1 = 1.1029 + 0.0880\ \mathrm{F_1} - 2.2719\ \mathrm{S} \qquad (3)$$

$$L_s / y_1 = 4.512 + 0.4160\ \mathrm{F_1} - 10.2877\ \mathrm{S} \qquad (4)$$

Figures (5a,b) show a comparison between the measured d_s/y_1 and L_s/y_1 and the predicted ones using Eqs. (3) and (4), respectively and an acceptable agreement can be noticed, to some extent. The residuals of the previous equations are plotted versus the predicted values as shown in (6a,b). The residuals show random distribution around the line of zero. The regression statistics have been listed in the table (1).

Table (1): The Regression Statistics

Regression Statistics	Eq. (3)	Eq. (4)
Multiple R	0.934	0.950
R Square	0.873	0.903
Adjusted R Square	0.867	0.899
Standard Error	0.106	0.422
Max. R. Absolute error	00.34	0.506
Average R. Absolute Error	0.089	0.099

CONCLUSIONS

An experimental study was carried out to control the scour activities DS of the vertical gate using a modified guide walls in a trapezoidal cross section channel. The conclusions of this study may be presented as follows:

- It was found that the different scour parameters ds/y_1 and Ls/y_1 increase as F_1 increases,
- Generally, it was found that the guide walls minified the different scour parameters compared to the no-guide wall case,
- Generally, it can be said that, the cross section of side slope *S* = 0.29 at presence of guide walls ((b_o/b =0.31, and t/b =3.1%) reduced the relative scour parameters to minimum limit within the experimental range of the study.
- The results of the proposed empirical equations are compared to the experimental measurements and an acceptable agreement has been found within 10% average absolute relative error.

NOMENCLATURE

b	clear stilling basin width	[L]
b_o	length of opening in the guide wall	[L]
d_s	maximum scour depth	[L]
F_1	initial Froude number	[-]
G	gate opening	[L]
H_U	US water depth	[L]
L_b	stilling basin length	[L]
L_s	maximum protection length	[L]
S	cross section side slope	[-]
t	guide wall thickness	[L]
V_1	mean velocity at the initial depth	$[LT^{-1}]$
y_1	initial depth of hydraulic jump	[L]
y_2	sequent depth of hydraulic jump	[L]
α	deflection angle of guide walls	[degree]
ρ	water density	$[ML^{-3}]$
ν	kinematics' viscosity	$[L^2T^{-1}]$

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ANNEX A

FIGURES

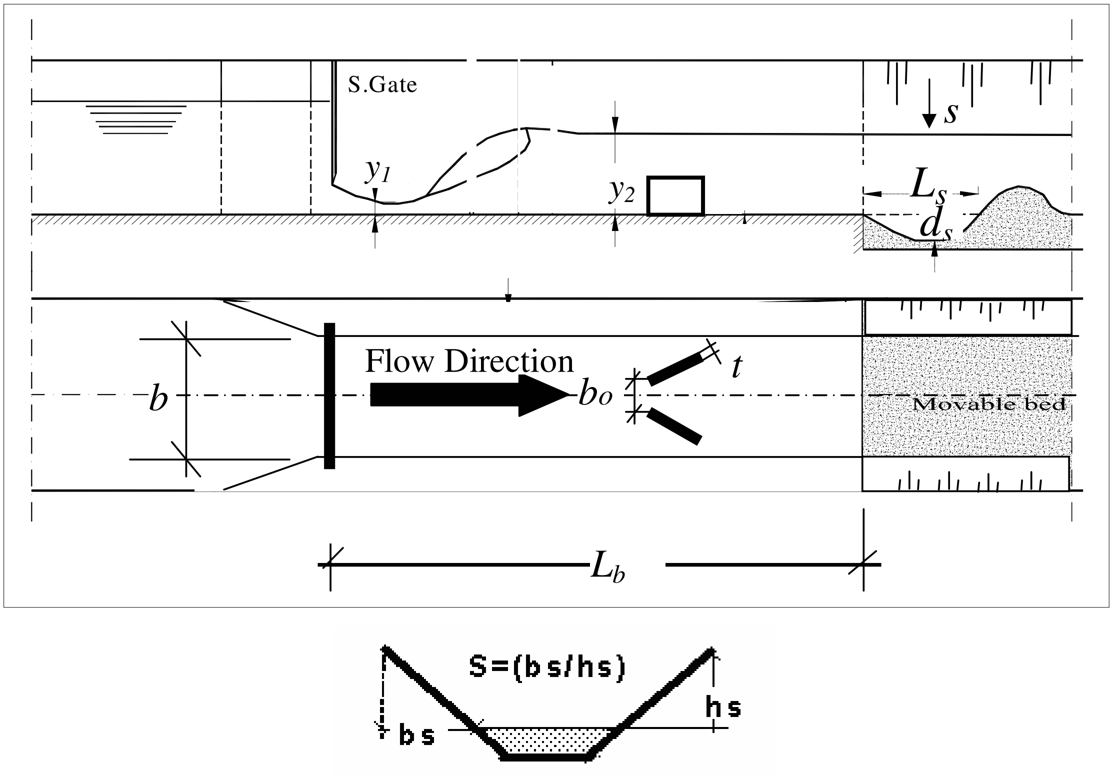

Fig. 1: Definition sketch for the test model and the trapezoidal section

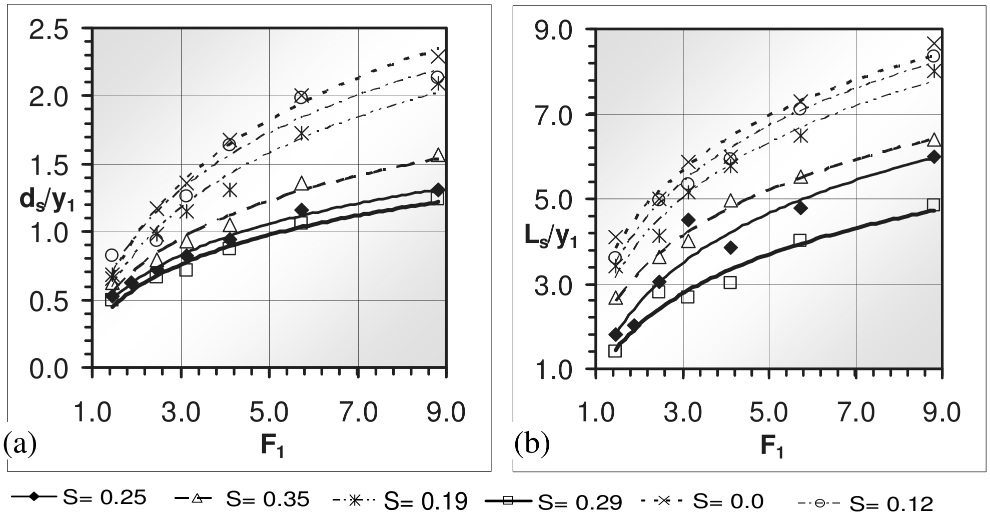

Fig. 2: Relationship between F_1 and [a]d_s/y_1 [b]L_s/y_1 for different s, (at b_o/b =0.31, and t/b =3.1%)

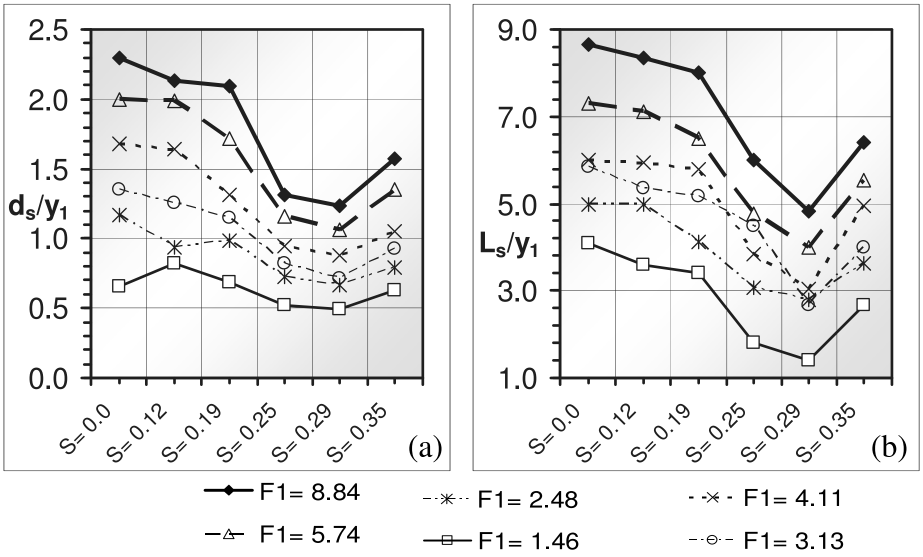

Fig. 3: Relationship between s and [a]d_s/y_1 [b]L_s/y_1[a]d_s/y_1 [b]L_s/y_1 for different F_1, (at b_o/b =0.31, and t/b =3.1%)

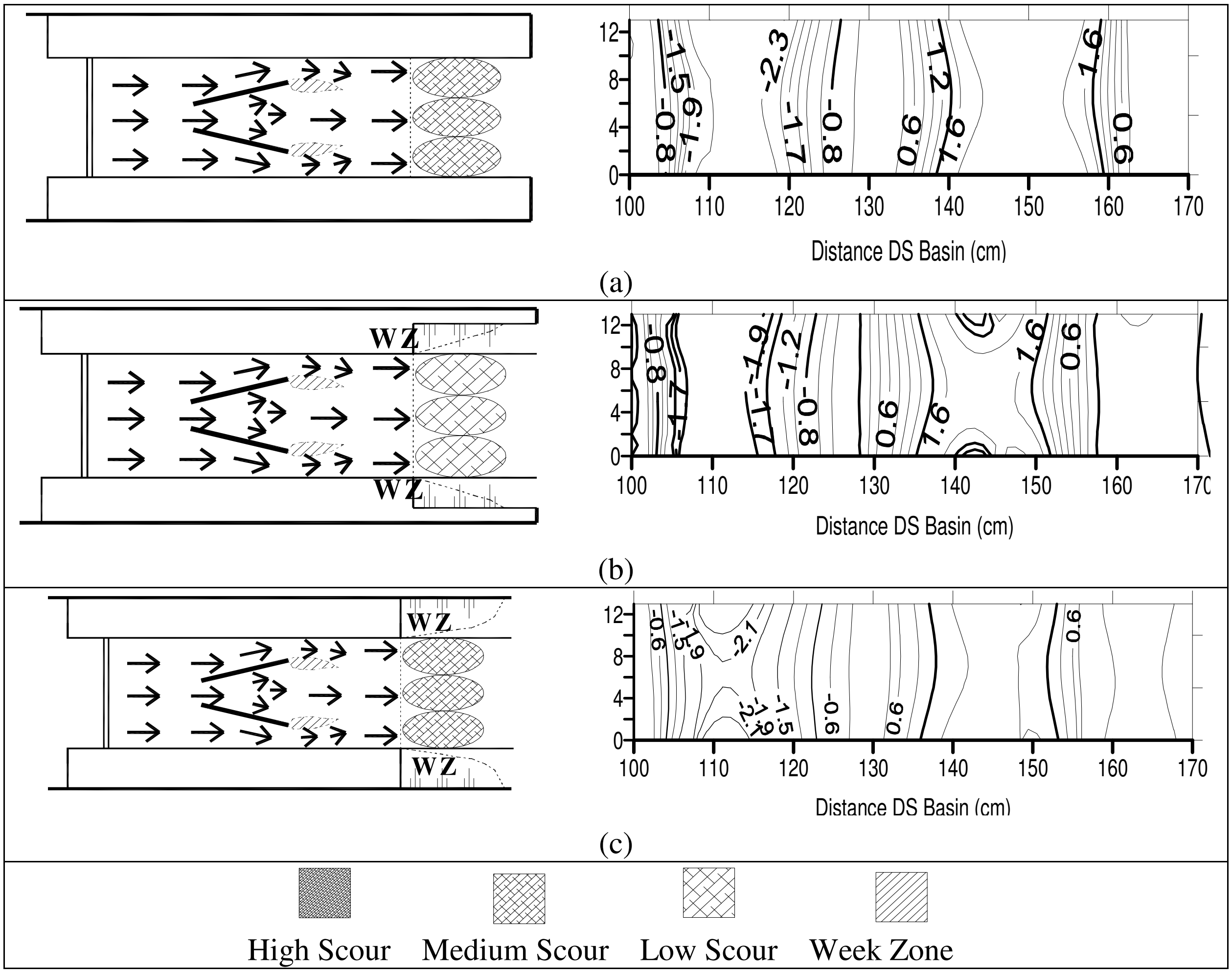

Fig. 4: Flow and scour patterns for different s, at F_1= 3.13 [a] s = 0.0 [b] s = 0.29 [c] s = 0.35

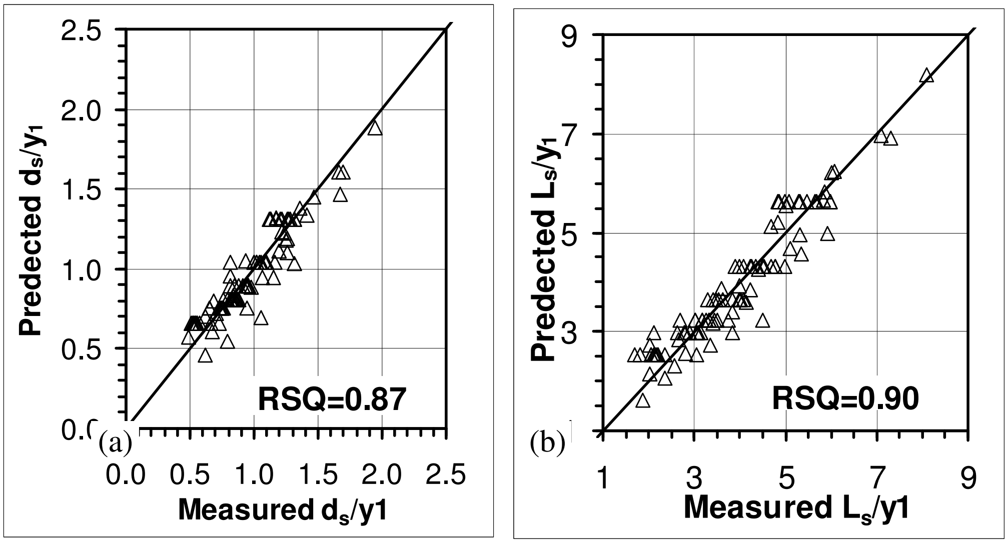

Fig. 5: Measured and predicted data for all experiential data [a]d_s/y_1 [b]L_s/y_1

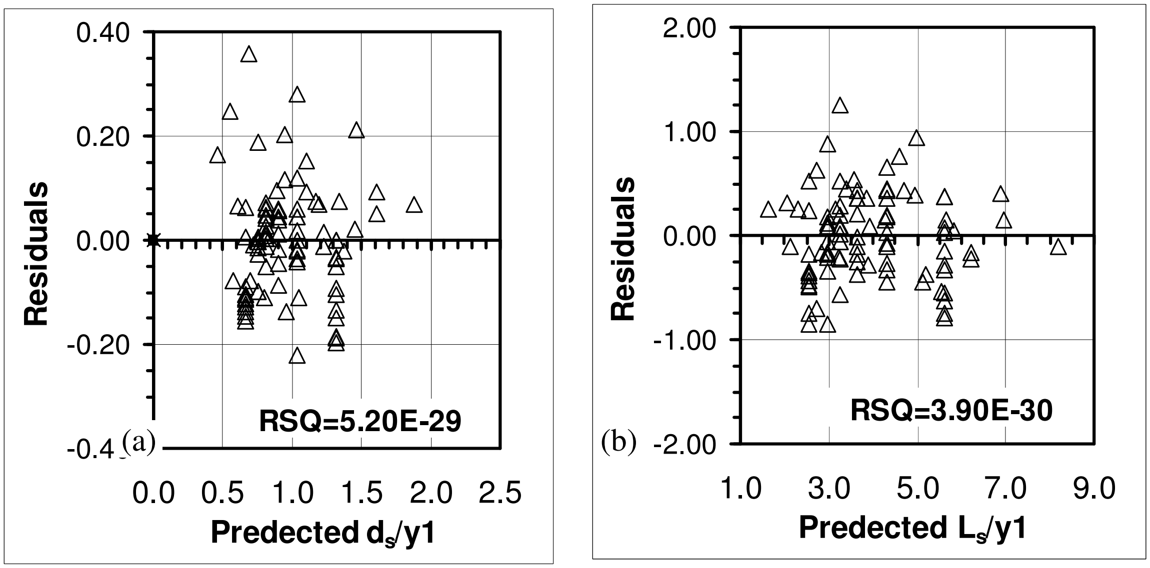

Fig. 6: Predicted data versus the residuals for all experiential data [a]d_s/y_1 [b]L_s/y_1